Symposium

Using Ecological Theory to Guide the Implementation of Augmentative Restoration[1]

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Abstract: Successful control of invasive plants can have unexpected effects on native plants and wildland systems. Therefore, it is important for managers of invasive species to be concerned with ecological mechanisms and processes like invasion resistance, environmental heterogeneity, and succession that direct plant community dynamics. Augmentative restoration is a management approach for restoring desired species on wildlands dominated by invasive plants, where functioning ecological processes are maintained by selectively augmenting only those processes that are not operating sufficiently. The study was conducted within the Mission Valley, Montana, in an area where meadow vole disturbance provided site availability for colonization. In a split-plot design with four replications, eight factorial treatment combinations from three factors (shallow tilling, watering, and seeding) were applied to whole plots, and 2,4-D was applied to subplots. Cover and density of seeded species, spotted knapweed, and sulfur cinquefoil were sampled in July 2002 and 2003 to produce pretreatment and posttreatment data. Analysis of covariance was used to analyze cover and density data using pretreatment data as a baseline covariate. Data indicated that in areas with adequate site availability due to meadow vole disturbance, seeding and watering without tilling were required to increase seeded species. Spotted knapweed and sulfur cinquefoil decreased in response to 2,4-D. These data provided evidence that augmentative restoration may improve our ability to establish desired species on invasive plant–dominated wildlands.

Nomenclature: 2,4-D; spotted knapweed, *Centaurea maculosa* Lam.; sulfur cinquefoil, *Potentilla recta* L.

Additional index words: Environmental heterogeneity, invasive weeds, native plant establishment, successional management.

Abbreviations: ANCOVA, analysis of covariance.

INTRODUCTION

Successful control of invasive plants can have unexpected effects on native plants and wildland systems. Therefore, it is important for managers of invasive species to be concerned about ecological mechanisms and processes like invasion resistance, environmental heterogeneity, and succession that direct plant community dynamics. Establishing and maintaining invasion-resistant plant communities involve restoring functionally diverse species that promote continuous resource capture, making fewer resources available for invasive species (Carpinelli et al. 2004; Fargione et al. 2003; Pokorny 2002). Environmental heterogeneity is considered by many ecologists a valuable ecological mechanism that can help explain and predict species composition and even maintain functionally diverse species in many systems (Huston 1994; Loreau et al. 2003; Pickett and Cadenasso 1995). Successional processes regulate plant community change over time. By manipulating successional processes, plant communities may be directed toward functionally diverse, weed-resistant populations (Sheley and Krueger-Mangold 2003; Sheley et al. 1996; Whisenant 1999).

Augmentative restoration is a management approach for restoring desired plant communities on wildlands dominated by invasive species, which is based on theories of invasion resistance, environmental heterogeneity, and succession. We define augmentative restoration as a strategy that enhances ecological processes occurring at sufficient levels by selectively augmenting those processes that occur at inadequate levels to direct plant com-

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Table 1. Causes of succession, contributing processes, and modifying factors.[a]

Causes of succession	Controlling processes	Modifying factors
Site availability	Disturbance	Size, severity, time intervals, patchiness, predisturbance history
Species availability	Dispersal	Dispersal mechanisms and landscape features
	Propagules	Land use, disturbance interval, species life history
Species performance	Resources	Soil, topography, climate, site history, microbes, litter retention
	Ecophysiology	Germination requirements, assimilation rates, growth rates, genetic differentiation
	Life history	Allocation, reproduction timing and degree
	Stress	Climate, site history, prior occupants, herbivory, natural enemies
	Interference	Competition, herbivory, allelopathy, resource availability, predators, other level interactions

[a] Modified from Pickett et al. (1987).

to half of every plot with a backpack sprayer. In late October 2002, plots were rototilled to a depth of 5 cm, and plots were broadcast seeded at a rate of 34 kg/ha. The seed mixture consisted of six grasses (17 kg/ha) and five forbs (17 kg/ha), including bluebunch wheatgrass (5 kg/ha), rough fescue (5 kg/ha), prairie junegrass (*Koeleria cristata* Pers.) (1.75 kg/ha), Baltic rush (*Juncus balticus* Willd.) (1.75 kg/ha), Sandburg's bluegrass (*Poa sandbergii* Vasey) (1.75 kg/ha), western wheatgrass (*Agropyron smithii* Rydb.) (1.75 kg/ha), indian blanket flower (*Gaillardia aristata* Pursh.) (3.4 kg/ha), sticky geranium (*Geranium viscosissimum* F. & M.) (3.4 kg/ha), common yarrow (*Achillea millefolium* L.) (3.4 kg/ha), silky lupine (*Lupinus sericeus* Pursh) (3.4 kg/ha), and wild bergamot (*Monarda fistulosa* L.) (3.4 kg/ha). These species represented key functional groups within the habitat type. In May, June, and July 2003, watering treatments were applied so that one-third (135 mm) the average annual precipitation (400 mm) was added.

Sampling. Plots were sampled for percent bare ground and percent soil moisture in 2002 before treatments were added and again in 2003 after treatments were added. Percent bare ground was estimated in July within two randomly placed Daubenmire frames (0.10 m²) per subplot. Percent soil moisture was sampled in three random locations per whole plot from May to August within the upper 15 cm of the soil profile using time domain reflectometry (Jones et al. 2002). Cover and density of seeded species, spotted knapweed, and sulfur cinquefoil were estimated in July 2002 before treatments were added and again in July 2003 after treatments were added. Percent cover and density of plant species were estimated within two randomly placed Daubenmire frames (0.10 m²) in each subplot.

Data Analysis. ANOVA was used to determine plot to plot variation in soil moisture before treatments were added. After treatments were added, ANOVA was used to determine the response of watering on soil moisture.

ANOVA was used to determine plot to plot variation in percent bare ground before treatments were added. Analysis of covariance (ANCOVA) was used to determine the response of seeding, watering, and shallow tilling on seeded species, spotted knapweed, and sulfur cinquefoil density and cover. Pretreatment cover and density data were used as a baseline covariate. Cover and density data were square root transformed to meet assumptions of ANOVA and ANCOVA, and Fisher's LSD procedure ($\alpha = 0.05$) was used to compare means.

RESULTS AND DISCUSSION

The management of wildland systems dominated by invasive species must move toward the restoration of ecological mechanisms and processes that support the reestablishment of sustainable, invasion-resistant plant communities (Sheley and Krueger-Mangold 2003; Zavaleta et al. 2001). Augmentative restoration uses successional theory to guide the implementation of restoration strategies that use existing ecological processes that are functioning adequately by augmenting processes that are operating insufficiently. Before treatments were added, the study site had high percent bare ground (55%) because of meadow vole disturbance, low soil moisture because of the upland position (24% in May), and low cover of native species (11%). We hypothesized that site availability was adequate because of vole disturbance, but the level of soil moisture and abundance of desired species were insufficient and would require augmentation to support the establishment of a desired plant community. Our data indicated that the treatment combination of seeding and watering increased seeded species cover ($P = 0.0273$) from 2 to 9% and density ($P < 0.0001$) from 18 to 120 stems/m² (Figure 1), whereas tilling did not significantly affect seeded species cover ($P = 0.9626$) or density ($P = 0.9236$). Spotted knapweed and sulfur cinquefoil density ($P = 0.0121$) decreased from 50 to 20 stems/m² in response to 2,4-D.
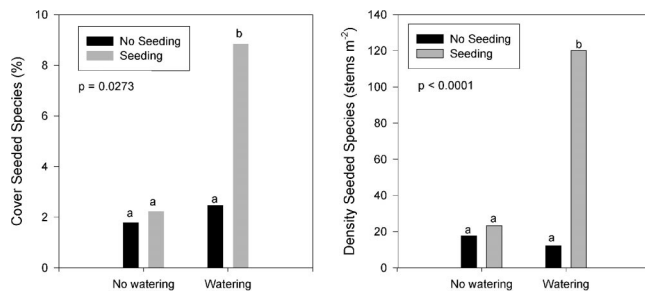
Figure 1. Percent cover and density of seeded species in response to the combination of seeding and watering treatments.

These data provided strong evidence in support of our hypotheses, indicating the importance of developing invasive plant management strategies that augment ecological mechanisms and processes when restoring desired plant communities. Further research could investigate the application of augmentative restoration to landscapes that vary spatially in factors influencing successional processes. For example, within one landscape, vole disturbances could be abundant in some areas and devoid in others (Rebollo et al. 2003), whereas soil moisture could be adequate in one area and insufficient in another (Berlow et al. 2003). Similarly, desired species abundance could be adequate for natural colonization in particular patches and devoid in others (Whisenant 1999). Augmentative restoration may provide a framework for guiding the development of treatment combinations that vary in response to the ecological variation in the landscape. This approach may preserve existing heterogeneity and diversity, which may improve the establishment and maintenance of functionally diverse, weed-resistant plant communities (Huston 1994).

Augmentative restoration may provide managers with a framework that enables them to identify variation in successional processes and to make strategic, site-specific decisions. Wildland managers often adapt farming practices uniformly across the landscape in an attempt to establish native species. Although using farming practices may be successful for establishing many nonnative species, it is becoming increasingly clear that native species require techniques based on an understanding of the ecological mechanisms and processes directing their success (Sheley and Krueger-Mangold 2003; Whisenant 1999). Our data provided initial evidence that augmentative restoration may improve our ability to establish native species on invasive plant–dominated wildlands because it addresses the ecological causes of plant succession.

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